Pergamon

PII: S0003-4878(00)00093-4

Ann. occup. Hyg., Vol. 45, No. 4, pp. 257–273, 2001

Printed in Great Britain.
0003-4878/01/$20.00

Temporal, Personal and Spatial Variability in Dermal Exposure

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A database of dermal exposure measurements (DERMDAT) comprising data from 20 surveys was created. The majority of dermal exposure measurements were from agricultural settings in which workers' exposure to pesticides was investigated. Other data came from studies of workers exposed to polycyclic aromatic hydrocarbons (e.g. coke-oven workers and paving workers) and from studies of subjects exposed to complex mixtures (rubber industry). The database contains approximately 6400 observations.

Grouping the workers by job title, factory and body location and excluding groups with more than 25% data below the limit of detection, or with less than two workers with at least two repeats, resulted in 283 groups with 1065 workers and 2716 measurements.

Analyses of variability showed median values of the total, within- and between-worker geometric standard deviations of respectively 2.55, 1.98 and 1.47, strikingly similar to what has been published previously for respiratory exposure. Within-worker variability (${}_{w}S^2{}_{y}$) was in general higher than between-worker variability (${}_{b}S^2{}_{y}$) in dermal exposure levels. Agricultural groups of re-entry workers showed very little to no between-worker variability, while industrial groups did show some variability in individual mean exposures (range ${}_{b}S^2{}_{y}$=0.15−0.29). When the between-body-location component (${}_{bl}S^2{}_{y}$) was also addressed, it turned out to be the most prominent component (median ${}_{b}S^2{}_{y}$=0.004; median ${}_{w}S^2{}_{y}$=0.12; median ${}_{bl}S^2{}_{y}$=0.34). In agriculture the between-body-location component was smaller than in industry. Day-to-day variability in dermal exposure levels appeared to be significant for specific locations, but not for the average of several body-locations. Underlying exposure scenarios (transfer and deposition) also played an important role. © 2001 British Occupational Hygiene Society. Published by Elsevier Science Ltd. All rights reserved

Keywords: dermal exposure; database; variance components

INTRODUCTION

The field of dermal exposure to chemicals emerged from agriculture and was directed to exposure to pesticides (Durham and Wolff, 1962). Developments of measurement methods for dermal exposure have been slow when compared to the developments for exposure to particulate matter and gases and vapours. While for instance the measurement of particulate matter was standardised and design and performance of different samplers reviewed, measurement of pesticides on the skin has basically stayed the same for more than four decades (Durham and Wolff, 1962; OECD, 1997). For measurement strategies we see a similar picture, with developments for respiratory exposures from worst-case approaches to more elaborate sampling strategies that take into account within- and between-worker components of exposure variability (Lyles *et al*., 1997). Measurement strategies for dermal exposure hardly exist and have been predominantly developed for registration purposes of pesticides. Starting with the WHO and EPA protocols in the eighties (WHO, 1982; US-EPA, 1985) only fairly recently a new guidance document from OECD was published (OECD, 1997). Structural attention to temporal and personal variability in exposure measurements has been almost entirely absent. The distribution of exposure over the body has on the contrary, been extensively studied. The main reason for

Received 17 June 2000; in final form 15 November 2000.
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this has been that estimates of total body uptake through the skin were needed for risk assessment purposes. Some anecdotal evidence of between- and within-worker variability in dermal exposure can nonetheless be found in the literature. Stamper *et al.* (1986) reported significant but not extreme variation in average dermal exposure levels between 10 harvesters measured on six consecutive days (Tuesday–Tuesday in a two-week period). They attributed this variation to differences in work practices among workers harvesting tree crops. Fenske (1993) claimed that because of highly variable source strength due to decomposition of pesticides and differences in work practices and hygienic behaviour both within- and between-person variability of dermal exposure in agricultural settings will be greater than that of corresponding respiratory exposures. A few years later OECD stated that 'the inherent variability in (dermal) exposure under field conditions is best addressed by increasing the number of subjects, rather than repeated monitoring of the same individuals, as variability between workers is generally greater than that encountered when monitoring the same worker' (OECD, 1997). However, de Cock *et al.* (1998) showed for 126 re-entry workers from 32 fruit farms that between-body-location variability was the largest variance component, followed by day-to-day variability and differences between tasks. Between-worker variability in average exposure was absent, when adjusted for these other variance components.

In the WAUNC database (Kromhout *et al.*, 1993) some dermal measurements were available mainly from the rubber manufacturing industry. These measurements showed a larger total variability than respiratory exposures, due to increased between-worker differences. The authors like Fenske (1993), suggested differences in personal behaviour to be responsible for this phenomenon.

Nigg and Stamper (1985) concluded more than a decade ago that knowledge of sources of variation encountered in dermal exposure studies would be helpful to design more rational field studies. In order to get a better understanding of the temporal (day-to-day), personal (between-worker) and spatial (between-body-locations) variability a database (named DERMDAT) was constructed of about 6400 dermal exposure measurements from a variety of industries. All measurements were personal measurements and sampling took place either at more than one body-location, or on at least two occasions. This paper describes the database, summarises the variance components, and describes factors that contributed significantly to these variances. This information was used to give guidance for future measurement strategies.

MATERIALS AND METHODS

The database was created out of existing field studies and comprises the data from 20 surveys. The data sets were collected from literature ($N = 1$), from the archives of our own group ($N = 11$) or were provided by other research groups ($N = 8$). Most of the studies ($N = 13$) have been published in the open literature (Boleij *et al.*, 1991; Brouwer *et al.*, 2000; de Cock *et al.*, 1998; Kromhout *et al.*, 1994; Nigg *et al.*, 1984; van Rooij *et al.*, 1993, 1994; van Wendel de Joode *et al.*, 1996; Vermeulen *et al.*, 2000a,b). Data were collected between 1982 and 1999. The database was elaborated by the authors either from the actual papers or data sets provided by the researchers. The database consists of the variables listed in Table 1. The authors coded the variables after consulting the original researchers.

Variance components were estimated in two ways. First for each group defined by job code and location (factory or farm), having at least two workers with at least two measurements per worker, the within- and between-worker variance components (respectively ${}_{\mathrm{w}}S^2{}_{\mathrm{y}}$ and ${}_{\mathrm{b}}S^2{}_{\mathrm{y}}$) were estimated for each body-location measured. Groups with more than 25% of their observations below the limit of detection were excluded. Secondly, for the groups with measurements of multiple body-locations measured for more than one day the between-body-location variance component (${}_{\mathrm{bl}}S^2{}_{\mathrm{y}}$) was estimated in addition.

The one-way analysis-of-variance (ANOVA) methods, which were used to estimate the components of variance, have been described extensively elsewhere (Kromhout *et al.*, 1993). From the variance components the ratios of the 97.5th and 2.5th percentiles of the log-normally distributed exposures for each group were estimated. These ratios designated $R._{95}$'s provided information regarding the ranges of exposures experienced between workers (${}_{\mathrm{b}}R._{95}$) and within workers from day-to-day (${}_{\mathrm{w}}R._{95}$), respectively (Rappaport, 1991).

The nested two-way analysis-of-variance model has also been described previously (Kromhout and Heederik, 1995). In this model day is supposed to be nested in a worker and body-location in both worker and day. The ANOVA table resulting from such a model enables estimation of three variance components, the between-worker variance, the pooled day-to-day variance and the pooled between-body-location variance.

The distributions of the variance components and $R._{95}$'s were evaluated by stratifying for several variables, including measurement strategy, monitoring method, exposure scenario and production and environmental characteristics. Wilcoxon's rank sum test (Snedecor and Cochran, 1980) was used to test the significance of shifts of location in the distributions of the variance components.

All statistical analyses were performed with SAS System for Windows (version 6.12) (SAS Institute, 1990).

Table 1. Information present in the DERMDAT database

Variable	Description
Set	Unique number
Origin	Research group
Country	Country of origin
Factory	Unique number
Industry	International Standard Industrial Classification (ISIC)
Job	Description of job
Job code	Original coding of job title
Occupation	International Standard Classification of Occupations (ISCO)
Date	Date of measurement
Worker	Unique identity number
Type	Type of exposure (agent)
Compartment	Compartment sampled (e.g. skin, clothing)[a]
Scenario	Scenario of the mass transport process (e.g. deposition, transfer from surface to skin, transfer from surface to clothing, transfer clothing to skin, etc.)[a]
Body location	Body location that is sampled (e.g. head, neck, upper arms, wrists, hands, etc.)
Method	Sampling method (pads, gloves, hand wash, VITEA etc.)
Concentration	Measured mass per surface area or time unit
Detection limit	Below (=0) or at or above (=1) detection limit
Unity	Unit of measurement (μg/cm^2/8 h; μg/cm^2; μg/h)
Sampling time	Duration of measurement
Sample of workers	Non-random (=0); random (=1); volunteers (=2); everybody (=3)
Sample of days	Non-random (=0); random (=1); fixed days (=2); all days (=3)
Environment	Outdoors (=0); indoors (=1) (most of the time)
Local exhaust ventilation	Not present (=0); present (=1)
Process	Intermittent (=0); continuous (=1)
Mobility of worker	Stationary (=0); mobile (=1)
Mobility of source	Stationary (=0); mobile (=1)
Source	Local (=0); general (=1)

[a]Adapted from Schneider *et al.* (1999)

RESULTS

In Table 2 the basic characteristics of the DERMDAT database are shown. Twenty-two measurement series from almost 900 workers yielded 6410 observations. The number of groups defined by job title, factory (farm) and body-location was 322. The majority of the studies, groups and measurements originated from The Netherlands (respectively 75, 90 and 80%). The agricultural sector and the rubber manufacturing industry provided more than 90% of the groups.

Table 3 presents the measurement strategy characteristics that were used to collect the dermal exposure data. Surrogate skin methods were the method of preference (93%). Measurements with pads were the most popular sampling method (87%). Removal techniques accounted for 5% of all measurements and another 3% of the data were collected applying the VITEA technique (Fenske and Birnbaum, 1997). The skin compartment was measured in 84% of the observations. In 56% of the measurements either transfer from contaminated surfaces (36%) or direct deposition or emission (20%) to the uncovered skin was monitored. In 28% of the measurements dermal exposure due to transfer from contaminated clothing to the skin was measured. Measuring everybody on random days was the preferred measurement strategy (38%) and the majority of the measurements took place indoor (66%). Duration of sampling showed a distinct bimodal distribution with 20% of the measurements lasting less than 1 h and 25% more than 8 h.

Large differences were apparent between industries for the number of repeats from day-to-day and the number of repeats on a given day (multiple body-locations). In the studies in rubber manufacturing on average only one body-location was measured, while the studies in agriculture, coke production and the asphalt industry measured on average 6–7 body-locations. Generally the studies typically lasted for one week only. In more than half of the dermal exposure measurements pesticides were involved, while cyclohexane soluble matter and polycyclic aromatic hydrocarbons were the other main exposures present in the database.

Grouping the workers by job title, factory (farm) and body-location and excluding groups based on the criteria mentioned earlier left 283 groups with 1065 workers and 2716 measurements (Appendix A). These groups came from only 12 of the original 20 studies. Four studies, all from the agricultural sector, had only one person at each farm being measured. Four other studies had no repeated measurements in time, but only repeated measurements within a particular day (multiple body-locations).

In Fig. 1 the cumulative distribution of the between- and within-worker values of the $R_{.95}$'s are shown for these 283 groups. Almost 40% of the groups had 95% of the individual mean exposures (per body location) within a factor 2 ($_bR_{.95} \leq 2$). On the other hand, almost 35% of the groups had values of $_bR_{.95} > 10$ and 15% of the groups had $_bR_{.95} > 50$. In general the day-to-day variability exceeded the between-worker variability, indicating larger temporal differences in exposure than between workers with the same job title and factory (farm). The median values of the total, within- and between-worker geo-

Table 2. Basic characteristics of the DERMDAT database

Number of surveys	20
Number of measurements series	22
Number of groups[a]	322
Number of workers	899
Number of observations	6410

Country	*No. of studies*	*No. of groups*	*No. of measurements*
The Netherlands	15 (75%)	291 (90%)	5111 (80%)
Costa Rica	2 (10%)	7 (2%)	262 (4%)
Italy	1 (5%)	10 (3%)	539 (8%)
USA	1 (5%)	2 (1%)	230 (4%)
UK	1 (5%)	12 (4%)	268 (4%)

ISIC	*Industry*	*No. of measurements*	*No. of groups*
111	Agriculture	3320 (52%)	178 (55%)
331	Wood preservation	68 (1%)	2 (1%)
354	Coke production	663 (10%)	6 (2%)
355	Rubber manufacturing	1541 (24%)	120 (37%)
372	Primary aluminium industry	80 (1%)	1 (0.3%)
3842	Offshore metal construction	168 (3%)	3 (1%)
5000	Asphalt industry	570 (9%)	12 (4%)

[a]Defined by job title and factory (farm)

metric standard deviations were respectively, 2.55, 1.98 and 1.47.

From Table 4 it is clear that for all exposure scenarios except for exposure by transfer from contaminated surfaces to clothing the median $_{b}R_{.95}$ is below 6. Of the 29 groups where the clothing compartment was measured and for which transfer from contaminated surfaces was the main route of exposure, 23 came from a study among sheep dippers. In this data set up to three workers on each farm were classified as having a similar job title (sheep dipper) and location (farm). However, distinct tasks (chucking, paddling and helping) could be attributed to each of them, explaining the very high between-worker differences for this scenario.

Groups, for which transfer from contaminated surfaces to the skin was the main route of exposure, were further studied by industry and measurement method (Table 5). Strikingly no between-worker variability was seen for the agricultural groups, while for the industrial groups the $_{b}R_{.95}$ varied between 4 and 8. The hand wash method showed less day-to-day variability than the pad method both in agricultural and the asphalt industry. For the rubber industry temporal differences were seen in estimates of the variance components over a 9-yr period while sampling in the same companies. The between-worker variance component decreased over time, while the within-worker component considerably increased.

The distribution of the variance components of measurements of transfer from surfaces to the skin with pads (103 groups) were further studied by stratified analyses for the influence of measurement strategy, environmental and production factors (Table 6). A random measurement strategy resulted in increased between-worker variability (median factor of 3). Indoor measurements also showed increased between-worker variability (median factor of 6). A local source also led to larger between-worker differences (median factor of 7). No statistically significant effect was seen for 'type of process' and 'worker mobility'. Hardly any influence was seen of all these parameters on the day-to-day variability.

The results of the two-way random effects ANOVA models are presented in Table 7. It is obvious from Table 7 that differences between-body-locations are the main source of variability. The day-to-day variability for each body-location separately, as shown in Table 4 (median $_{w}S^2_{y} = 0.47$), appears to disappear when more than one body-location is being measured at one time and when results are averaged across body-locations (median $_{w}S^2_{y} = 0.02$). For the hand wash method with only two body-locations (both hands) this was not the case. The large between-worker variability shown for measurements with pads of the clothing compartment was largely determined by eight groups of sheep dippers.

DISCUSSION

The elaborated database described in our paper offered the opportunity to study between- and within worker components of dermal exposure to pesticides and other chemical agents both in agriculture and

Table 3. Measurement strategy characteristics of the database

Sampling methods		
Surrogate skin		
Pads	5594 (87%)	
Undergarments	130 (2%)	
Overall	130 (2%)	
Gloves	41 (1%)	
Hair band	8 (0.1%)	
Removal techniques		
Hand wash	286 (4%)	
Wet wipe	53 (1%)	
Fluorescence techniques		
VITEA	168 (3%)	
Compartments measured		
Skin	5408 (84%)	
Outer clothing	1002 (16%)	
Scenario measured		
Transfer surface to skin	2327 (36%)	
Transfer clothing to skin	1775 (28%)	
Deposition/emission to skin	1306 (20%)	
Transfer surface to clothing	560 (9%)	
Deposition/emission to clothing	442 (7%)	
Measurement strategy		
Everybody/random days	2414 (38%)	
Volunteers/fixed days	1334 (21%)	
Random workers/fixed days	814 (13%)	
Random workers/random days	736 (11%)	
Other	1112 (17%)	
Environment measured		
Indoors	4224 (66%)	
Outdoors	2186 (34%)	
Sampling duration		
20% less than 1 h		
Median at 6.5 h		
25% more than 8 h		
Bimodal distribution		
Industry	*# days mean (range)*	*# body-locations mean (range)*
Agriculture	1.7 (1–6)	7.3 (1–22)
Rubber manufacturing	2.7 (1–4)	1.1 (1–9)
Cokes production	4.9 (4–5)	5.6 (3–6)
Asphalt industry	1.8 (1–4)	7.4 (1–10)
Agents	*No. (%)*	
Pesticides	3320 (52%)	
Cyclohexane soluble fraction	1572 (24%)	
PAH	1350 (21%)	
Paint	168 (3%)	

industry. In addition between-body-location variability in dermal exposure could be studied as well. Unfortunately, the number of measurement series available was somewhat limited and in addition measurement methods and strategies appeared to be closely linked to the particular exposure situation. Therefore the picture emerging from this database is far less comprehensive than the picture for respiratory exposure that emerged from another database that was published some years ago (Kromhout *et al.*, 1993).

Nevertheless comparison of median estimates of both total, within- and between-worker geometric standard deviations for groups defined by job title and location (factory or farm) are strikingly similar for dermal exposure when compared to respiratory exposure (2.55 vs 2.41, 1.98 vs 2.00 and 1.47 vs 1.43). There appeared to be no evidence for earlier suggestions in the literature that the between-worker variability for dermal exposure would be larger than for respiratory exposures. Also similar to respiratory exposures, dermal exposures (for a particular body-

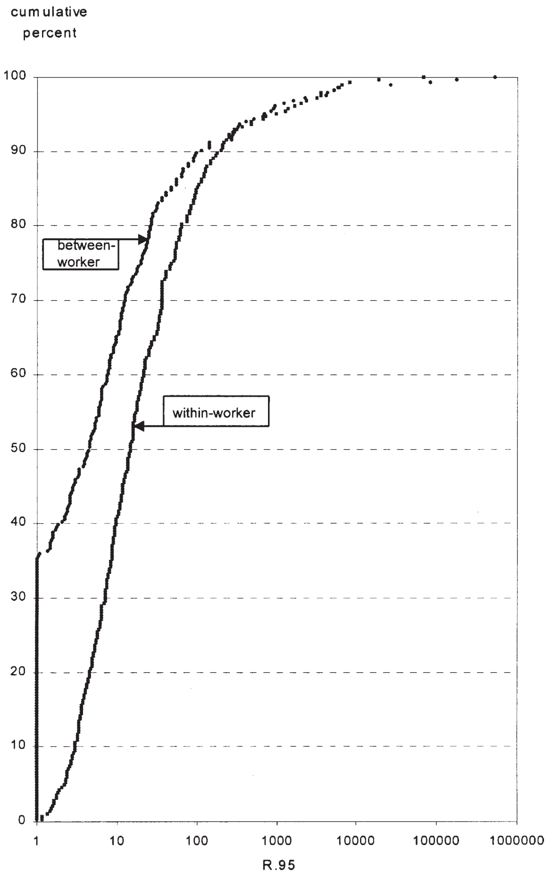

Fig. 1. Cumulative distributions of ${}_{b}R_{.95}$ and ${}_{w}R_{.95}$ for all 283 groups defined by job title, factory (farm) and body location.

location) tend to vary more from day to day than between workers. This refutes the OECD suggestion that for dermal exposure the variability between workers is generally greater than that encountered when monitoring the same worker. The notion that the between-body-location variance component was the largest as suggested by de Cock *et al.* (1998) in a study among fruit harvesters was further corroborated in our study with similar evidence from other agricultural and industrial studies. However, it was also shown that body-location variability was less than the day-to-day variability when the hand wash method was applied. The fact that only two similar body-locations (both hands) are measured and the fact that the total skin area represented by this method is 100%, instead of a few percent when using dermal pads, explains this finding.

The results for the transfer of contamination from surfaces to the skin revealed that between-worker variability within groups of workers in agriculture was absent (see Table 5). The most likely explanation for this phenomenon can be traced to the fact that most of these agricultural groups consisted of re-entry workers with similar task contents and an omnipresent source of contamination (dislodgeable foliar residue). In industrial situations more variability in average dermal exposure was present between workers from the same group that can presumably be related to more differentiation in task contents and sources of exposure.

The results also show that part of the temporal variability can be accounted for by the sampling method applied. The surrogate skin pad method exhibited more day-to-day variability than the hand wash method most likely due to non-uniform distribution of exposure for a specific body location in combination with the relatively small surface area of the pad. This implies that more repeated measurements should be taken over time when applying the pad method than when the hand wash method is being used. Larger pads (as has been suggested by OECD) or multiple pads are an alternative solution. The two-way analysis of variance showed that the temporal variance component disappeared when multiple pads were used on different body-locations simultaneously. With no real temporal variability present (the apparent temporal variability is caused by sampling error), it is expected that production and environmental factors showed no influence on the day-to-day variability. The differences in average dermal exposure of individual workers on the contrary were influenced by these variables and measurement strategy related variables. These findings are in sharp contrast with

Table 4. Median results of the one-way random effects ANOVA for groups defined by job title, factory (farm) and body location[a]

Scenario	No. of groups	${}_{b}S^2_y$	${}_{b}R_{.95}$	${}_{w}S^2_y$	${}_{w}R_{.95}$
All	283	0.15	4.5	0.47	14.5
Transfer SS	135	0.09	3.3	0.50	16.1
Transfer CS	81	0.08	3.1	0.42	12.8
Transfer SC	29	2.03	270	0.63	22.6
Sheep dipping	23	2.18	328	0.79	32.4
Re-entry	6	0.25	7.1	0.33	9.6
Deposition	38	0.20	5.7	0.33	9.6

[a]SS: surface to skin; CS: clothing to skin; SC: surface to clothing. ${}_{b}S^2_y$: between-worker variance; ${}_{b}R_{.95}$: ratio of the 97.5th and 2.5th percentiles of the between-worker distribution; ${}_{w}S^2_y$: within-worker variance; ${}_{w}R_{.95}$: ratio of the 97.5th and 2.5th percentiles of the within-worker distribution

Table 5. Median results of the one-way random effects ANOVA for groups defined by job title, factory (farm) and body location for the transfer surface to skin (Transfer SS) scenario[a]

Industry method	No. of groups	${}_{b}S^2_y$	${}_{b}R_{.95}$	${}_{w}S^2_y$	${}_{w}R_{.95}$
All	135	0.09	3.3	0.50	16.1
Agriculture					
Pads	20	0.00	1.0	0.84	36.5
Hand wash	24	0.00	1.0	0.31	8.7
Rubber					
Pads 1998	50	0.29	8.1	0.49	15.6
Pads 1997	15	0.15	4.5	0.82	34.6
Coke oven					
Pads	8	0.21	6.0	0.46	14.2
Asphalt					
Pads	6	0.18	5.5	0.23	6.5
Hand wash	5	0.16	4.7	0.13	4.1

[a] ${}_{b}S^2_y$: between-worker variance; ${}_{b}R_{.95}$: ratio of the 97.5th and 2.5th percentiles of the between-worker distribution; ${}_{w}S^2_y$: within-worker variance; ${}_{w}R_{.95}$ ratio of the 97.5th and 2.5th percentiles of the within-worker distribution

Table 6. Median results of the one-way random effects ANOVA for groups defined by measurement strategy, environmental and production factors (for 103 groups with surface to skin transfer (Transfer SS) scenario measured with pads only)[a]

Factor	No. of groups	${}_{b}S^2_y$	${}_{b}R_{.95}$	${}_{w}S^2_y$	${}_{w}R_{.95}$
Strategy					
Random	50	0.29	8.1*	0.49	15.6
Non-random	53	0.06	2.6	0.65	23.5
Environment					
Indoor	79	0.23	6.4**	0.52	17.3
Outdoor	24	0.00	1.0	0.65	23.6
Process					
Intermittent	18	0.25	7.2	0.44	13.5
Continuous	85	0.12	3.9	0.60	20.6
Source					
Local	69	0.25	7.2***	0.53	17.5
General	34	0.00	1.0	0.55	18.2
Worker					
Mobile	84	0.15	4.5	0.64	23.1
Stationary	19	0.06	2.6	0.52	16.7

[a] ${}_{b}S^2_y$: between-worker variance; ${}_{b}R_{.95}$: ratio of the 97.5th and 2.5th percentiles of the between-worker distribution; ${}_{w}S^2_y$: within-worker variance; ${}_{w}R_{.95}$: ratio of the 97.5th and 2.5th percentiles of the within-worker distribution. *$P<0.05$ **$P<0.01$ ***$P<0.001$

Table 7. Median results of the two-way random effects ANOVA for groups defined by job title and factory (farm)[a]

Method compartment	No. of groups	${}_{b}S^2_y$	${}_{b}R_{.95}$	${}_{w}S^2_y$	${}_{bl}S^2_y$
All	52	0.10	3.4	0.02	0.46
Hand wash					
Skin	10	0.00	1.0	0.26	0.13
Pads					
Clothing	10	1.47	118	0.00	2.44
Skin	31	0.06	2.7	0.02	0.61
Gloves	1	0.14	4.4	0.02	0.22

[a] ${}_{b}S^2_y$: between-worker variance; ${}_{b}R_{.95}$: ratio of the 97.5th and 2.5th percentiles of the between-worker distribution; ${}_{w}S^2_y$: within-worker variance; ${}_{bl}S^2_y$: between-body-location variance

the findings for inhalation exposures were basically the opposite was noticed (Kromhout *et al*., 1993).

Using estimates of variance components from earlier studies in similar industries or even the same companies turned out to be risky. The dermal exposure data from the rubber manufacturing industry appeared not to be stationary.

The DERMDAT database has very limited power for generalisation. The majority of the data comes from small groups (as small as one per farm) from agriculture. Therefore the estimates of the variance components will be very imprecise (Symanski *et al*., 1994). Furthermore, source strength in agriculture is often not stationary (Boleij *et al*., 1991). This could result in an increased day-to-day variability that would be less relevant for industrial exposure situations. Some evidence for increased temporal variability in dermal exposure in agriculture was apparent from our database. Also, purely random measurement strategies were very infrequently applied and as was shown this affected the variance components.

Further limitations were present with regard to compartments measured (skin and outer clothing), exposure scenarios (deposition, transfer) and measurement method (basically only one: surrogate skin).

So, in order to arrive at more general insights in dermal exposure variability and its consequences for measurement strategies more data should be made available or collected. Especially, more individuals should be measured per group, longer observation periods (>1 week) are needed and more 'true' random sampling strategies should be applied. Unfortunately, existing protocols are rather restrictive with regard to the above mentioned points. These protocols generate in general large amounts of quality control data (Fenske and Teschke, 1995) and most often the data is coming from semi-experimental settings. The existing protocols predominantly cater for regulatory agencies engaged in risk assessment of particular chemicals (e.g. pesticides). Dermal exposure assessment strategies for epidemiology and hazard control should, however, be developed based on knowledge of temporal, personal and spatial variability. Regrettably, a comprehensive picture of these crucial factors is still far away. Prospective epidemiological studies and studies focusing on hazard control should therefore, for the time being, start with pilot studies to determine these factors in order to optimise exposure assessment methods and strategies. The implications of the estimated variance components for the actual measurement strategy will depend on whether systemic or local effects of dermal exposure are being studied. In addition, de Cock *et al*. (1995) have suggested that penetration rates might be different for specific body locations. Considerations like these will next to the variance components, eventually determine the measurement strategy for a particular study on dermal exposure.

Acknowledgements—The authors would like to acknowledge Derk Brouwer, Igor Burstyn, Anna Cenni, John Cherrie, Johan de Cock, Herbert Nigg and Joost van Rooij for making data available. Without the input of former EOH students Berna van Wendel de Joode, Inge de Graaf, Mark Fleuren, Wim Tieleman, Govert Verstappen, Kees van Dijk, Marjan Smink, Peter Tamsma, Hillie Dillema, Angelo Rutten, Olaf Spruyt and Mathieu van Puijvelde who collected extensive amounts of dermal exposure data, this database would not have surfaced. The Skin and Surface Contamination sub-group of the EU-Dermal Exposure Network provided the stimulating environment from which the idea for this database emerged. This work was facilitated by the Dermal Exposure Network, supported by European Commission Contract SMT4-4CT96-7502 (DG12-RSMT).

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APPENDIX A

Table A.1. Characteristics of 283 groups (based on job title, factory and body-location)

Group	k[a]	N[b]	${}_{w}S_{y}$[c]	${}_{w}R_{.95}$[d]	${}_{b}S_{y}$[e]	${}_{b}R_{.95}$[f]	Chemical agent	Industry	Body-location	Compartment	Scenario	Method
1	9	26	0.651	12.8	0.736	17.9	chlorobenzilate	fruit growing	back	skin	transcs	pads
2	9	27	0.637	12.1	1.153	91.7	chlorobenzilate	fruit growing	chest	skin	transcs	pads
3	9	23	0.668	13.7	0.803	23.3	chlorobenzilate	fruit growing	forearm left lower	skin	transcs	pads
4	9	27	0.855	28.5	0.468	6.3	chlorobenzilate	fruit growing	hand	skin	transss	hand wash
5	9	25	0.528	7.9	0.520	7.7	chlorobenzilate	fruit growing	lower leg	clothing	transsc	pads
6	9	26	1.004	51.2	0.569	9.3	chlorobenzilate	fruit growing	shoulder	skin	transcs	pads
7	9	27	0.630	11.8	0.847	27.7	chlorobenzilate	fruit growing	upper arm	skin	transcs	pads
8	9	26	0.676	14.2	0.476	6.5	chlorobenzilate	fruit growing	upper leg	clothing	transsc	pads
9	3	9	1.223	120.9	0.000	1.0	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
10	7	20	1.407	248.6	0.000	1.0	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
11	3	7	1.064	64.8	0.000	1.0	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
12	7	19	1.056	62.9	0.616	11.2	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
13	9	24	0.787	21.9	0.724	17.1	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
14	5	13	1.097	73.7	0.136	1.7	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
15	6	18	1.294	159.8	0.948	41.1	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
16	8	22	0.419	5.2	0.349	3.9	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
17	4	9	0.906	34.9	1.717	838.8	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
18	8	22	0.352	4.0	0.980	46.7	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
19	8	22	0.915	36.1	0.560	9.0	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
20	4	10	1.233	125.8	1.112	78.1	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
21	3	9	1.250	134.3	0.737	17.9	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
22	6	13	2.239	6473.0	0.306	3.3	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
23	3	8	0.444	5.7	1.263	141.1	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
24	2	6	0.831	26.0	0.000	1.0	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
25	5	14	1.014	53.2	1.442	285.1	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
26	5	12	1.155	92.4	0.000	1.0	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
27	4	11	0.701	15.6	1.027	56.0	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
28	7	19	0.551	8.7	0.582	9.8	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
29	3	8	0.371	4.3	0.532	8.0	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
30	6	14	0.321	3.5	0.874	30.8	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
31	2	6	0.694	15.2	1.435	277.4	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
32	3	8	0.678	14.3	0.114	1.6	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
33	5	14	0.883	31.9	0.746	18.6	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
34	9	25	0.701	15.6	0.653	12.9	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
35	2	5	0.467	6.2	0.264	2.8	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
36	2	6	0.795	22.6	0.000	1.0	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
37	12	27	0.567	9.2	0.000	1.0	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
38	2	6	0.522	7.7	0.000	1.0	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
39	2	6	0.462	6.1	0.475	6.4	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads

Table A.1. Continued

Group	k[a]	N[b]	${}_{w}S_{y}$[c]	${}_{w}R_{.95}$[d]	${}_{b}S_{y}$[e]	${}_{b}R_{.95}$[f]	Chemical agent	Industry	Body-location	Compartment	Scenario	Method
40	2	5	0.514	7.5	0.219	2.4	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
41	8	23	1.134	85.4	1.066	65.2	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
42	2	7	1.129	83.5	0.000	1.0	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
43	10	27	0.898	33.7	0.847	27.7	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
44	6	14	0.729	17.5	0.563	9.1	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
45	3	6	1.153	91.9	1.269	144.8	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
46	3	8	1.104	75.7	0.000	1.0	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
47	3	9	0.228	2.4	0.534	8.1	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
48	9	27	0.592	10.2	0.606	10.7	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
49	2	6	0.352	4.0	0.019	1.1	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
50	2	6	0.391	4.6	0.364	4.2	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
51	5	14	0.306	3.3	0.110	1.5	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
52	9	21	0.567	9.2	0.767	20.2	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
53	15	41	0.576	9.6	0.535	8.1	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
54	16	40	0.611	11.0	0.627	11.7	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
55	7	19	0.727	17.3	0.242	2.6	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
56	3	7	0.634	12.0	0.272	2.9	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
57	4	10	0.545	8.5	0.693	15.1	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
58	2	6	0.598	10.4	0.199	2.2	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
59	5	14	0.904	34.6	0.839	26.8	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
60	12	33	0.891	32.9	0.578	9.6	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
61	7	19	0.375	4.3	0.381	4.4	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
62	3	9	0.342	3.8	1.147	89.7	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
63	4	11	0.806	23.5	0.384	4.5	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
64	4	12	1.067	65.5	1.484	335.5	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
65	2	5	0.915	36.1	0.000	1.0	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
66	4	12	0.825	25.3	0.000	1.0	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
67	3	9	0.506	7.3	0.605	10.7	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
68	2	6	0.920	36.8	0.000	1.0	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
69	10	29	1.011	52.6	0.382	4.5	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
70	2	6	1.164	95.9	0.000	1.0	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
71	3	9	1.019	54.3	0.114	1.6	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
72	9	25	0.919	36.8	0.389	4.6	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
73	14	40	0.434	5.5	0.772	20.6	dermal csf	rubber manufacturing	wrist lower	skin	transss	pads
74	6	11	0.498	7.0	0.878	31.2	dermal csf	asphalt industry	wrist left lower	skin	transss	pads
75	7	14	0.708	16.1	0.000	1.0	dermal csf	asphalt industry	wrist right lower	skin	transss	pads
76	3	8	0.763	19.9	0.866	29.8	paraquat	fruit growing	back	skin	transcs	pads
77	3	8	0.918	36.5	0.822	25.1	paraquat	fruit growing	upper leg left	skin	deposit	pads
78	3	8	0.795	22.6	0.922	37.1	paraquat	fruit growing	wrist left lower	skin	deposit	pads

Continued overleaf

Table A.1. Continued

Group	k[a]	N[b]	${}_{w}S_{y}$[c]	${}_{w}R_{.95}$[d]	${}_{b}S_{y}$[e]	${}_{b}R_{.95}$[f]	Chemical agent	Industry	Body-location	Compartment	Scenario	Method
79	3	8	0.496	7.0	0.820	24.9	paraquat	fruit growing	wrist right lower	skin	deposit	pads
80	2	6	0.896	33.5	0.000	1.0	paraquat	fruit growing	back	skin	transcs	pads
81	2	6	0.298	3.2	0.507	7.3	paraquat	fruit growing	wrist left lower	skin	deposit	pads
82	2	6	0.608	10.9	0.000	1.0	paraquat	fruit growing	wrist right lower	skin	deposit	pads
83	3	8	0.110	1.5	0.405	4.9	paraquat	fruit growing	upper leg left	skin	transcs	pads
84	3	8	0.387	4.6	0.000	1.0	paraquat	fruit growing	wrist left lower	skin	deposit	pads
85	3	8	0.524	7.8	0.334	3.7	paraquat	fruit growing	wrist right lower	skin	deposit	pads
86	3	6	0.263	2.8	0.000	1.0	paraquat	fruit growing	forehead	skin	transcs	pads
87	3	6	0.745	18.6	0.000	1.0	paraquat	fruit growing	upper leg left	skin	transcs	pads
88	3	6	0.539	8.3	0.414	5.1	paraquat	fruit growing	wrist left lower	skin	transcs	pads
89	3	6	0.473	6.4	0.000	1.0	paraquat	fruit growing	wrist right lower	skin	transcs	pads
90	2	10	0.794	22.5	0.761	19.8	benzoapyrene	coke industry	ankle left	skin	transcs	pads
91	2	9	0.532	8.0	0.353	4.0	benzoapyrene	coke industry	ankle left	skin	transcs	pads
92	3	14	0.409	5.0	0.844	27.4	benzoapyrene	coke industry	ankle left	skin	transcs	pads
93	3	13	0.275	2.9	0.151	1.8	benzoapyrene	coke industry	ankle left	skin	transcs	pads
94	2	10	0.764	20.0	0.000	1.0	benzoapyrene	coke industry	neck/Jaw left	skin	deposit	pads
95	2	9	0.440	5.6	0.121	1.6	benzoapyrene	coke industry	neck/Jaw left	skin	deposit	pads
96	3	15	0.821	25.0	0.311	3.4	benzoapyrene	coke industry	neck/Jaw left	skin	deposit	pads
97	3	15	1.187	104.8	0.000	1.0	benzoapyrene	coke industry	neck/Jaw left	skin	deposit	pads
98	2	9	1.511	373.6	0.000	1.0	benzoapyrene	coke industry	shoulder left	skin	transcs	pads
99	2	7	0.423	5.2	0.212	2.3	benzoapyrene	coke industry	shoulder left	skin	transcs	pads
100	3	14	1.145	89.1	0.000	1.0	benzoapyrene	coke industry	shoulder left	skin	transcs	pads
101	3	12	0.945	40.7	0.000	1.0	benzoapyrene	coke industry	shoulder left	skin	transcs	pads
102	2	10	0.737	18.0	1.886	1621.9	benzoapyrene	coke industry	thigh left	skin	transcs	pads
103	2	9	0.663	13.4	0.516	7.6	benzoapyrene	coke industry	thigh left	skin	transcs	pads
104	3	12	0.918	36.5	0.075	1.3	benzoapyrene	coke industry	thigh left	skin	transcs	pads
105	3	14	0.973	45.4	0.452	5.9	benzoapyrene	coke industry	thigh left	skin	transcs	pads
106	2	10	0.556	8.8	0.237	2.5	benzoapyrene	coke industry	upper arm	skin	transcs	pads
107	2	9	0.894	33.3	0.000	1.0	benzoapyrene	coke industry	upper arm	skin	transcs	pads
108	3	13	1.348	197.0	0.000	1.0	benzoapyrene	coke industry	upper arm	skin	transcs	pads
109	3	13	0.511	7.4	0.098	1.5	benzoapyrene	coke industry	upper arm	skin	transcs	pads
110	2	10	0.718	16.7	0.425	5.3	benzoapyrene	coke industry	wrist left lower	skin	transss	pads
111	2	9	0.772	20.6	0.000	1.0	benzoapyrene	coke industry	wrist left lower	skin	transss	pads
112	3	14	0.509	7.4	0.000	1.0	benzoapyrene	coke industry	wrist left lower	skin	transss	pads
113	3	15	0.564	9.1	0.885	32.1	benzoapyrene	coke industry	wrist left lower	skin	transss	pads
114	2	9	0.623	11.5	0.207	2.3	pyrene	coke industry	ankle left	skin	transcs	pads
115	2	8	0.223	2.4	0.000	1.0	pyrene	coke industry	ankle left	skin	transcs	pads
116	3	15	0.913	35.8	0.394	4.7	pyrene	coke industry	ankle left	skin	transcs	pads
117	3	14	0.160	1.9	0.092	1.4	pyrene	coke industry	ankle left	skin	transcs	pads

Table A.1. Continued

Group	k[a]	N[b]	$_{w}S_{y}$[c]	$_{w}R_{.95}$[d]	$_{b}S_{y}$[e]	$_{b}R_{.95}$[f]	Chemical agent	Industry	Body-location	Compartment	Scenario	Method
118	2	10	0.278	3.0	0.000	1.0	pyrene	coke industry	neck/Jaw left	skin	deposit	pads
119	2	9	1.892	1661.5	0.000	1.0	pyrene	coke industry	neck/Jaw left	skin	deposit	pads
120	3	15	0.555	8.8	0.000	1.0	pyrene	coke industry	neck/Jaw left	skin	deposit	pads
121	3	15	0.879	31.3	0.808	23.7	pyrene	coke industry	neck/Jaw left	skin	deposit	pads
122	2	9	1.171	98.7	0.097	1.5	pyrene	coke industry	shoulder left	skin	transcs	pads
123	2	7	1.573	476.2	0.000	1.0	pyrene	coke industry	shoulder left	skin	transcs	pads
124	3	15	1.022	55.0	0.000	1.0	pyrene	coke industry	shoulder left	skin	transcs	pads
125	3	13	1.014	53.2	0.430	5.4	pyrene	coke industry	shoulder left	skin	transcs	pads
126	2	10	0.383	4.5	1.970	2259.6	pyrene	coke industry	thigh left	skin	transcs	pads
127	2	9	0.704	15.8	0.309	3.4	pyrene	coke industry	thigh left	skin	transcs	pads
128	3	15	0.597	10.4	1.027	56.1	pyrene	coke industry	thigh left	skin	transcs	pads
129	3	15	0.612	11.0	0.945	40.6	pyrene	coke industry	thigh left	skin	transcs	pads
130	2	10	1.048	60.8	0.649	12.7	pyrene	coke industry	upper arm	skin	transcs	pads
131	2	9	0.784	21.6	0.012	1.1	pyrene	coke industry	upper arm	skin	transcs	pads
132	3	12	0.472	6.4	0.472	6.4	pyrene	coke industry	upper arm	skin	transcs	pads
133	3	14	0.765	20.0	1.023	55.2	pyrene	coke industry	upper arm	skin	transcs	pads
134	2	9	0.261	2.8	0.486	6.7	pyrene	coke industry	wrist left lower	skin	transss	pads
135	2	9	0.914	35.9	0.503	7.2	pyrene	coke industry	wrist left lower	skin	transss	pads
136	3	14	1.055	62.6	0.000	1.0	pyrene	coke industry	wrist left lower	skin	transss	pads
137	3	14	0.629	11.8	0.702	15.6	pyrene	coke industry	wrist left lower	skin	transss	pads
138	2	4	2.841	68518.9	0.000	1.0	paraquat	fruit growing	lower leg left	skin	transcs	pads
139	2	4	0.892	33.0	0.000	1.0	paraquat	fruit growing	upper leg left	skin	transcs	pads
140	2	4	1.364	209.8	0.285	3.1	paraquat	fruit growing	lower leg left	skin	transcs	pads
141	2	4	0.982	47.0	0.000	1.0	paraquat	fruit growing	upper arm left lower	skin	transcs	pads
142	2	4	0.553	8.7	0.839	26.9	paraquat	fruit growing	upper leg left	skin	transcs	pads
143	6	21	0.553	8.7	0.470	6.3	methomyl	vegetable growing	hand	skin	transss	hand wash
144	7	10	0.335	3.7	0.434	5.5	methomyl	vegetable growing	hand	skin	transss	hand wash
145	5	10	1.317	174.9	0.000	1.0	methomyl	vegetable growing	hand	skin	transss	hand wash
146	2	4	0.359	4.1	0.475	6.4	captan	fruit growing	hand left	skin	transss	hand wash
147	2	4	0.544	8.4	0.429	5.4	captan	fruit growing	hand right	skin	transss	hand wash
148	2	4	0.843	27.2	0.000	1.0	captan	fruit growing	wrist left lower	skin	transss	pads
149	2	4	0.643	12.4	0.000	1.0	captan	fruit growing	wrist right lower	skin	transss	pads
150	3	4	0.624	11.6	0.648	12.7	captan	fruit growing	chest	clothing	transsc	pads
151	3	4	0.094	1.4	1.072	67.0	captan	fruit growing	forearm left upper	clothing	transsc	pads
152	3	4	0.914	36.0	0.000	1.0	captan	fruit growing	hand left	skin	transss	hand wash
153	3	4	0.298	3.2	0.616	11.2	captan	fruit growing	hand right	skin	transss	hand wash
154	3	4	1.211	115.5	0.000	1.0	captan	fruit growing	wrist left lower	skin	transss	pads
155	3	4	0.037	1.2	1.162	95.1	captan	fruit growing	wrist right lower	skin	transss	pads
156	2	4	0.186	2.1	0.181	2.0	captan	fruit growing	chest	clothing	transsc	pads

Continued overleaf

Table A.1. Continued

Group	k[a]	N[b]	${}_{w}S_{y}$[c]	${}_{w}R_{.95}$[d]	${}_{b}S_{y}$[e]	${}_{b}R_{.95}$[f]	Chemical agent	Industry	Body-location	Compartment	Scenario	Method
157	2	4	1.942	2026.6	0.000	1.0	captan	fruit growing	forearm left upper	skin	transss	pads
158	2	4	1.319	176.2	0.000	1.0	captan	fruit growing	forehead	skin	deposit	pads
159	2	4	0.935	39.1	0.000	1.0	captan	fruit growing	hand left	skin	transss	hand wash
160	2	4	0.666	13.6	0.000	1.0	captan	fruit growing	hand right	skin	transss	hand wash
161	2	4	2.296	8094.6	0.000	1.0	captan	fruit growing	wrist left lower	skin	transss	pads
162	2	4	1.659	667.9	0.000	1.0	captan	fruit growing	wrist right lower	skin	transss	pads
163	2	4	0.553	8.7	0.000	1.0	captan	fruit growing	hand left	skin	transss	hand wash
164	2	4	1.375	219.6	0.000	1.0	captan	fruit growing	hand right	skin	transss	hand wash
165	2	4	0.666	13.6	0.000	1.0	captan	fruit growing	wrist left lower	skin	transss	pads
166	2	4	0.769	20.4	0.781	21.3	captan	fruit growing	wrist right lower	skin	transss	pads
167	3	4	1.364	209.6	0.000	1.0	captan	fruit growing	hand left	skin	transss	hand wash
168	3	4	1.180	101.9	0.000	1.0	captan	fruit growing	hand right	skin	transss	hand wash
169	3	4	0.551	8.7	0.633	11.9	captan	fruit growing	wrist left lower	skin	transss	pads
170	3	4	0.079	1.4	0.248	2.6	captan	fruit growing	wrist right lower	skin	transss	pads
171	4	5	0.443	5.7	0.000	1.0	captan	fruit growing	hand left	skin	transss	hand wash
172	4	5	0.507	7.3	0.000	1.0	captan	fruit growing	hand right	skin	transss	hand wash
173	4	5	1.451	294.9	0.000	1.0	captan	fruit growing	wrist left lower	skin	transss	pads
174	3	4	1.012	52.8	0.000	1.0	captan	fruit growing	forearm left upper	skin	transss	pads
175	3	4	0.403	4.9	0.000	1.0	captan	fruit growing	hand left	skin	transss	hand wash
176	3	4	0.383	4.5	0.000	1.0	captan	fruit growing	hand right	skin	transss	hand wash
177	3	4	0.922	37.1	0.000	1.0	captan	fruit growing	wrist left lower	skin	transss	pads
178	3	4	0.418	5.1	0.980	46.7	captan	fruit growing	wrist right lower	skin	transss	pads
179	2	4	1.761	994.3	0.000	1.0	captan	fruit growing	forearm left upper	clothing	transsc	pads
180	2	4	1.444	287.5	0.000	1.0	captan	fruit growing	hand left	skin	transss	hand wash
181	2	4	1.393	235.4	0.000	1.0	captan	fruit growing	hand right	skin	transss	hand wash
182	2	4	2.088	3581.3	0.000	1.0	captan	fruit growing	wrist left lower	skin	transss	pads
183	2	4	1.226	122.3	0.000	1.0	captan	fruit growing	forearm left upper	skin	transss	pads
184	2	4	0.472	6.4	0.000	1.0	captan	fruit growing	hand left	skin	transss	hand wash
185	2	4	0.579	9.7	0.282	3.0	captan	fruit growing	hand right	skin	transss	hand wash
186	2	4	0.914	36.0	0.000	1.0	captan	fruit growing	wrist left lower	skin	transss	pads
187	2	4	0.424	5.3	0.000	1.0	captan	fruit growing	wrist right lower	skin	transss	pads
188	2	4	0.308	3.3	0.141	1.7	captan	fruit growing	hand left	skin	transss	hand wash
189	2	4	0.471	6.3	0.000	1.0	captan	fruit growing	hand right	skin	transss	hand wash
190	2	4	2.178	5108.9	0.000	1.0	captan	fruit growing	wrist left lower	skin	transss	pads
191	2	4	0.681	14.4	0.000	1.0	total pah	asphalt industry	back	skin	transcs	pads
192	2	4	0.461	6.1	0.000	1.0	total pah	asphalt industry	calf back right	skin	transcs	pads
193	2	4	0.503	7.2	0.000	1.0	total pah	asphalt industry	calf front left	skin	transcs	pads
194	2	4	0.682	14.5	0.000	1.0	total pah	asphalt industry	chest	skin	transcs	pads
195	2	4	0.571	9.4	0.000	1.0	total pah	asphalt industry	forearm right	skin	transss	pads

Table A.1. Continued

Group	k[a]	N[b]	${}_{w}S_{y}$[c]	${}_{w}R_{.95}$[d]	${}_{b}S_{y}$[e]	${}_{b}R_{.95}$[f]	Chemical agent	Industry	Body-location	Compartment	Scenario	Method
196	2	4	0.570	9.4	0.000	1.0	total pah	asphalt industry	forehead	skin	deposit	pads
197	2	4	0.619	11.3	0.000	1.0	total pah	asphalt industry	hands	skin	transss	hand wash
198	2	4	0.701	15.6	0.000	1.0	total pah	asphalt industry	thigh left back	skin	transcs	pads
199	2	4	0.615	11.1	0.000	1.0	total pah	asphalt industry	thigh right	skin	transcs	pads
200	2	4	0.312	3.4	0.000	1.0	total pah	asphalt industry	upper arm left	skin	transcs	pads
201	2	4	0.314	3.4	0.259	2.8	total pah	asphalt industry	back	skin	transcs	pads
202	2	4	0.214	2.3	0.231	2.5	total pah	asphalt industry	calf back right	skin	transcs	pads
203	2	4	0.472	6.4	0.000	1.0	total pah	asphalt industry	calf front left	skin	transcs	pads
204	2	4	0.149	1.8	1.591	511.7	total pah	asphalt industry	chest	skin	transcs	pads
205	2	4	0.253	2.7	0.240	2.6	total pah	asphalt industry	forearm right	skin	transss	pads
206	2	4	0.951	41.6	0.222	2.4	total pah	asphalt industry	forehead	skin	deposit	pads
207	2	4	0.329	3.6	0.398	4.8	total pah	asphalt industry	hands	skin	transss	hand wash
208	2	4	0.152	1.8	0.452	5.9	total pah	asphalt industry	thigh left back	skin	transcs	pads
209	2	4	0.130	1.7	0.688	14.8	total pah	asphalt industry	thigh right	skin	transcs	pads
210	2	4	0.684	14.6	0.000	1.0	total pah	asphalt industry	upper arm left	skin	transcs	pads
211	5	10	1.569	469.1	0.000	1.0	total pah	asphalt industry	calf back right	skin	transcs	pads
212	5	10	0.409	5.0	0.238	2.5	total pah	asphalt industry	calf front left	skin	transcs	pads
213	5	10	1.045	60.1	0.559	8.9	total pah	asphalt industry	chest	skin	transcs	pads
214	5	10	0.752	19.1	0.597	10.4	total pah	asphalt industry	forearm right	skin	transcs	pads
215	5	10	0.631	11.8	0.433	5.5	total pah	asphalt industry	forehead	skin	deposit	pads
216	5	10	0.117	1.6	0.303	3.3	total pah	asphalt industry	hands	skin	transss	hand wash
217	5	9	0.301	3.3	0.819	24.8	total pah	asphalt industry	thigh left back	skin	transcs	pads
218	5	10	0.283	3.0	0.833	26.2	total pah	asphalt industry	thigh right	skin	transcs	pads
219	5	10	1.122	81.3	0.539	8.3	total pah	asphalt industry	upper arm left	skin	transcs	pads
220	4	11	1.825	1279.3	0.793	22.4	total pah	asphalt industry	calf back right	skin	transcs	pads
221	4	11	1.678	718.4	1.816	1234.8	total pah	asphalt industry	calf front left	skin	transcs	pads
222	4	10	1.163	95.5	2.212	5832.0	total pah	asphalt industry	forehead	skin	deposit	pads
223	4	11	0.735	17.8	1.067	65.7	total pah	asphalt industry	hands	skin	transss	hand wash
224	4	8	0.149	1.8	0.467	6.2	total pah	asphalt industry	back	skin	transcs	pads
225	4	8	0.510	7.4	0.000	1.0	total pah	asphalt industry	calf back right	skin	deposit	pads
226	4	8	0.216	2.3	0.458	6.0	total pah	asphalt industry	calf front left	skin	deposit	pads
227	4	8	0.478	6.5	0.000	1.0	total pah	asphalt industry	chest	skin	transcs	pads
228	4	8	0.455	5.9	1.262	141.0	total pah	asphalt industry	forearm right	skin	transss	pads
229	3	6	0.663	13.4	0.920	36.9	total pah	asphalt industry	forehead	skin	deposit	pads
230	4	8	0.327	3.6	0.509	7.4	total pah	asphalt industry	thigh left back	skin	deposit	pads
231	4	8	0.432	5.4	0.604	10.7	total pah	asphalt industry	thigh right	skin	deposit	pads
232	4	8	0.281	3.0	0.455	6.0	total pah	asphalt industry	upper arm left	skin	transcs	pads
233	6	10	0.207	2.2	0.651	12.8	total pah	asphalt industry	back	skin	transcs	pads
234	6	10	0.122	1.6	0.582	9.8	total pah	asphalt industry	calf back right	skin	deposit	pads

Continued overleaf

Table A.1. Continued

Group	k[a]	N[b]	${}_{w}S_{y}$[c]	${}_{w}R_{.95}$[d]	${}_{b}S_{y}$[e]	${}_{b}R_{.95}$[f]	Chemical agent	Industry	Body-location	Compartment	Scenario	Method
235	6	10	0.247	2.6	0.612	11.0	total pah	asphalt industry	calf front left	skin	deposit	pads
236	6	10	0.305	3.3	0.692	15.0	total pah	asphalt industry	chest	skin	transcs	pads
237	6	10	0.379	4.4	0.544	8.4	total pah	asphalt industry	forearm right	skin	transss	pads
238	6	10	0.246	2.6	0.626	11.6	total pah	asphalt industry	forehead	skin	deposit	pads
239	6	10	0.359	4.1	0.524	7.8	total pah	asphalt industry	hands	skin	transss	hand wash
240	6	10	0.370	4.3	0.833	26.2	total pah	asphalt industry	thigh left back	skin	deposit	pads
241	6	10	0.582	9.8	0.812	24.1	total pah	asphalt industry	thigh right	skin	deposit	pads
242	6	10	0.276	3.0	0.641	12.3	total pah	asphalt industry	upper arm left	skin	transcs	pads
243	5	6	0.715	16.5	0.000	1.0	dermal csf	rubber manufacturing	forearm left	skin	transcs	pads
244	6	9	0.821	25.0	0.000	1.0	dermal csf	rubber manufacturing	forearm right	skin	transcs	pads
245	7	9	0.731	17.5	0.000	1.0	dermal csf	rubber manufacturing	hand left	skin	transss	gloves
246	5	6	0.038	1.2	0.370	4.3	dermal csf	rubber manufacturing	hand right	skin	transss	gloves
247	7	14	1.122	81.2	0.000	1.0	dermal csf	rubber manufacturing	wrist left lower	skin	transss	pads
248	7	15	0.712	16.3	0.349	3.9	dermal csf	rubber manufacturing	wrist lower right	skin	transss	pads
249	5	10	0.329	3.6	0.622	11.4	dermal csf	rubber manufacturing	forearm right	skin	transcs	pads
250	5	9	0.785	21.7	0.801	23.1	dermal csf	rubber manufacturing	hand left	skin	transss	gloves
251	5	14	0.841	27.1	0.595	10.3	dermal csf	rubber manufacturing	wrist left lower	skin	transss	pads
252	5	14	0.558	8.9	0.528	7.9	dermal csf	rubber manufacturing	wrist lower right	skin	transss	pads
253	3	6	0.654	13.0	1.669	694.4	organophosphates	sheep dipping	chest	clothing	transsc	pads
254	3	5	0.950	41.5	3.079	174 540.0	organophosphates	sheep dipping	upper leg left	clothing	transsc	pads
255	2	4	1.240	129.1	0.000	1.0	organophosphates	sheep dipping	back	clothing	deposit	pads
256	2	4	0.331	3.7	2.130	4236.2	organophosphates	sheep dipping	chest	clothing	transsc	pads
257	2	4	0.703	15.7	1.468	316.2	organophosphates	sheep dipping	forearm left lower	clothing	transsc	pads
258	2	4	0.497	7.0	0.664	13.5	organophosphates	sheep dipping	forehead	clothing	deposit	pads
259	2	4	0.318	3.5	1.166	96.5	organophosphates	sheep dipping	upper leg left	clothing	transsc	pads
260	3	6	0.796	22.6	2.593	25 926.2	organophosphates	sheep dipping	chest	clothing	transsc	pads
261	3	6	0.858	28.9	0.666	13.6	organophosphates	sheep dipping	forearm left lower	clothing	transsc	pads
262	3	5	2.509	18 705.4	0.772	20.6	organophosphates	sheep dipping	forehead	clothing	deposit	pads
263	3	6	0.976	45.9	1.478	328.4	organophosphates	sheep dipping	upper leg left	clothing	transsc	pads
264	3	5	0.221	2.4	1.661	671.8	organophosphates	sheep dipping	chest	clothing	transsc	pads
265	3	6	1.023	55.1	0.000	1.0	organophosphates	sheep dipping	back	clothing	deposit	pads
266	3	6	1.203	111.9	1.431	273.0	organophosphates	sheep dipping	chest	clothing	transsc	pads
267	3	6	1.104	75.8	2.122	4102.0	organophosphates	sheep dipping	forearm left lower	clothing	transsc	pads
268	3	6	1.047	60.7	0.000	1.0	organophosphates	sheep dipping	forehead	clothing	deposit	pads
269	3	6	0.887	32.4	2.182	5187.9	organophosphates	sheep dipping	upper leg left	clothing	transsc	pads
270	3	6	1.270	145.1	0.000	1.0	organophosphates	sheep dipping	chest	clothing	transsc	pads
271	3	6	0.428	5.4	1.062	64.2	organophosphates	sheep dipping	forearm left lower	clothing	transsc	pads
272	3	6	0.740	18.2	1.532	405.2	organophosphates	sheep dipping	upper leg left	clothing	transsc	pads

Table A.1. Continued

Group	k[a]	N[b]	${}_{w}S_{y}$[c]	${}_{w}R_{.95}$[d]	${}_{b}S_{y}$[e]	${}_{b}R_{.95}$[f]	Chemical agent	Industry	Body-location	Compartment	Scenario	Method
273	2	4	2.221	6048.7	0.000	1.0	organophosphates	sheep dipping	chest	clothing	transsc	pads
274	2	4	0.754	19.2	2.891	83 533.0	organophosphates	sheep dipping	forearm left lower	clothing	transsc	pads
275	2	4	0.405	4.9	1.734	893.8	organophosphates	sheep dipping	forehead	clothing	deposit	pads
276	2	4	1.979	2337.9	0.000	1.0	organophosphates	sheep dipping	chest	clothing	transsc	pads
277	3	6	2.055	3147.7	1.749	947.9	organophosphates	sheep dipping	chest	clothing	transsc	pads
278	3	4	2.082	3503.7	0.000	1.0	organophosphates	sheep dipping	forearm left lower	clothing	transsc	pads
279	2	4	0.221	2.4	1.210	114.7	organophosphates	sheep dipping	back	clothing	deposit	pads
280	2	4	1.413	254.5	1.112	78.1	organophosphates	sheep dipping	chest	clothing	transsc	pads
281	2	4	1.274	147.7	3.362	529 618.8	organophosphates	sheep dipping	forearm left lower	clothing	transsc	pads
282	2	4	1.843	1371.3	0.000	1.0	organophosphates	sheep dipping	forehead	clothing	deposit	pads
283	2	4	0.703	15.8	1.427	268.8	organophosphates	sheep dipping	upper leg left	clothing	transsc	pads

[a] k, number of workers in a group
[b] N, number of measurements in a group
[c] ${}_{w}S_{y}$, estimated standard deviation of the within-worker distribution of log-transformed exposures
[d] ${}_{w}R_{.95}$, ratio of 97.5th and 2.5th percentiles of the within-worker distribution
[e] ${}_{b}S_{y}$, estimated standard deviation of the between-worker distribution of log-transformed exposures
[f] ${}_{b}R_{.95}$, ratio of 97.5th and 2.5th percentiles of the between-worker distribution